University of California - Davis

UCD-96-21
July, 1996

Detection of Neutral MSSM Higgs Bosons in Four-b Final States at the Tevatron and the LHC: An Update

J. Dai[a], J.F. Gunion[a], and R. Vega[c]

[a]*Physics Department, University of California, La Jolla, CA 92093, USA*
[b]*Davis Institute for High Energy Physics, University of California, Davis, CA 95616, USA*
[c]*Physics Department, Southern Methodist University, Dallas, TX 75275, USA*

Abstract

We update our earlier results regarding detection of $gg \to b\overline{b}h \to 4b$ ($h = h^0, H^0, A^0$) to incorporate the very high b-tagging efficiencies and purities that are now anticipated at the LHC. New results for the Tev* are given, and indicate substantial potential for these modes. The complementarity of the $H^0 \to h^0h^0 \to 4b$ final state mode is illustrated for the LHC. The latest radiative corrections to the Higgs sector are incorporated.

In an earlier paper [1] we explored the possibility of finding one or more of the neutral Higgs bosons of the minimal supersymmetric standard model (MSSM) in $gg \to b\overline{b}h$ ($h = h^0, H^0, A^0$) production followed by $h \to b\overline{b}$. Vastly superior b-tagging efficiency and purity is now deemed feasible at the LHC, relative to the conservative assumptions of the earlier work. Canonical values now employed by ATLAS and CMS [2] are: $e_{b-tag} \sim 0.6$ and $e_{mis-tag} \sim 0.01$ for $|\eta| \leq 2.5$ and $p_T \geq 15$ GeV at low luminosity (applicable for accumulated luminosity of $L = 30$ fb^{-1} per detector); and $e_{b-tag} \sim 0.5$ and $e_{mis-tag} \sim 0.02$ for $|\eta| \leq 2.5$ and $p_T \geq 30$ GeV at high luminosity ($L = 300$ fb^{-1} per detector accumulated).* Further, excellent b-tagging capabilities are now anticipated at the Tevatron upgrades, especially the Tev*. At an upgraded Tevatron with upgraded detectors, CDF and D0 now expect to achieve $e_{b-tag} \sim 0.5$ with $e_{mis-tag} \sim 0.005$ for jets with $p_T \gtrsim 15$ GeV and $|\eta| \leq 2$, at instantaneous luminosities capable of yielding $L = 10 - 30$ fb^{-1} per year [3]. At both the LHC and Tevatron detectors, it is now estimated that the probability for tagging a c-quark jet as a b-quark jet is $e_{c-tag} \sim e_{b-tag}/3$. In this note, we update our earlier LHC results to incorporate the improved b-tagging expectations, and give, in addition, new results for these same modes at the Tev*.

Our LHC computations for the $gg \to b\overline{b}h \to 4b$ modes employ 3-b-tagging and incorporate precisely the same cuts and procedures (with, in particular, approximate QCD K factors included) as outlined in Ref. [1] with the following exceptions. i) We present results for low-luminosity running ($L = 30$ fb^{-1} per detector) — the ATLAS+CMS signal significance is computed by combining rates for the two detectors, *i.e.* we assume $L = 60$ fb^{-1} summed luminosity. ii) Correspondingly, we employ the low-luminosity values of $e_{b-tag} = 0.6$ and $e_{mis-tag} = 0.01$, requiring that 3 jets with $p_T > 30$ GeV and $|\eta| \leq 2.5$ be tagged as b-quarks.

*The quantities e_{b-tag} and $e_{mis-tag}$ are, respectively, the probabilities for tagging a real b-jet and of mis-tagging a light-quark or gluon jet as a b-jet.

iii) The latest ('two-loop') radiative corrections to Higgs masses and mixing angles [4] are incorporated. iv) We have corrected our previous failure to include identical particle effects for the $gg \to b\overline{b}b\overline{b}$ background (effectively leading to a factor of ~ 2 too large a rate). v) We include the $b\overline{b}c\overline{c}$ background using $e_{c-tag} = e_{b-tag}/3$; this results in the $b\overline{b}c\overline{c}$ background being about 60% of the irreducible $b\overline{b}b\overline{b}$ background. Although b's could be tagged at low luminosity for p_T's as low as 15 GeV, we have found that requiring $p_T \geq 30$ GeV for tagged b's produces a higher statistical significance for the signal, especially at higher masses. 4-b-tagging is not advantageous for the $b\overline{b}h \to 4b$ discovery modes, since one of the b's produced in association with the Higgs tends to be soft. Our results are presented in Fig. 1.

In comparison to our earlier results, the region of parameter space at large $\tan\beta$ for which two of the MSSM Higgs bosons (either the h^0 and A^0, at low m_{A^0}, or the H^0 and A^0, at high m_{A^0}) can be observed now extends to much lower $\tan\beta$ values. In Fig. 1 we also illustrate the complementarity of the $gg \to b\overline{b}h \to 4b$ modes to the recently explored $gg \to H^0 \to h^0h^0, A^0A^0 \to 4b$ discovery channel [5]. The plotted discovery regions for the latter channel are obtained assuming low-luminosity running with $L = 30$ fb^{-1} for ATLAS and CMS — statistical significance is computed for ATLAS+CMS by combining rates for the two detectors. [For this channel, we require that four jets with $p_T \geq 15$ GeV and $|\eta| \leq 2.5$ be tagged as b-quarks (using $e_{b-tag} = 0.6$ and $e_{mis-tag} = 0.01$). For $e_{c-tag} \sim e_{b-tag}/3$ and *four* tags, the $b\overline{b}c\overline{c}$ background is negligible.] Together, the $b\overline{b}h \to 4b$ and $H^0 \to 4b$ final states allow discovery of one or more of the neutral MSSM Higgs bosons over a remarkably large portion of parameter space. Further improvements in b-tagging efficiency and, especially, purity would result in a narrowing of the inaccessible wedge apparent in Fig. 1 at moderate $\tan\beta$ which develops and widens as m_{A^0} increases.

High-luminosity LHC running might or might not be advantageous for the $gg \to b\overline{b}h \to 4b$ modes. At high luminosity, defined as $L = 600$ fb^{-1} for ATLAS+CMS, the nominal statistical significance of the $4b$ signal increases by about 50%, despite the poorer $e_{mis-tag} = 0.02$ mis-identification rate that enhances the dominant $b\overline{b}g$ background. However, as we discuss later, triggering on the $4b$ final state becomes more problematical. A large reduction in the triggering efficiency at high luminosity could result in little gain in statistical significance over low-luminosity running.

We have also explored the parameter space regions for which the $gg \to b\overline{b}h \to 4b$ channels can be detected at the Tevatron assuming that the Tev* upgrade achieves an integrated luminosity of $L = 30$ fb^{-1}, and that 3 jets with $p_T \geq 15$ GeV and $|\eta| \leq 2$ are tagged as b-quarks, taking $e_{b-tag} = 0.5$, $e_{c-tag} = e_{b-tag}/3$ and $e_{mis-tag} = 0.005$. The ability to achieve a very small mis-tagging probability for light-quark and gluon jets is crucial at the Tevatron, since the low event rates set a premium on eliminating the large $b\overline{b}g$ mis-tag background. All other procedures and cuts employed in our analysis are the same as at the LHC, and are given in Ref. [1]. Our results for center of mass energy $\sqrt{s} = 1.8$ TeV are displayed in Fig. 2. (Note the change in $\tan\beta$ scale relative to Fig. 1.) Although MSSM Higgs discovery at the Tev* in the $gg \to b\overline{b}h \to 4b$ channel is clearly limited to smaller m_{A^0} and/or much larger $\tan\beta$ values than at the LHC, a significant window of opportunity is apparent. Models with high $\tan\beta \sim 60$ can be probed for m_{A^0} values up to nearly 300 GeV. We note that

$gg \to H^0 \to h^0 h^0, A^0 A^0 \to 4b$ allows Higgs detection only in the $m_{A^0} \lesssim 60$ GeV region (but for all $\tan\beta \gtrsim 1.5 - 2$) at the Tev* [5].

Decays of the neutral Higgs bosons to SUSY pair states have been neglected in these computations. Such decays would have small branching ratio at high $\tan\beta$, but, if present, could reduce the extent of the discovery regions illustrated at low to moderate $\tan\beta$.

We caution that our analysis assumes that it will be possible to trigger on the $4b$ final states of interest with high efficiency. Various strategies are currently being studied by the CDF, D0, ATLAS and CMS collaborations. For the level-one trigger an acceptable data rate is achieved (even for high-luminosity running at the LHC) by simply requiring 3 jets with $p_T > 30$ GeV or 4 jets with $p_T > 15$ GeV [6], as needed in our $b\bar{b}h$ and $h^0 h^0$ analyses, respectively. The real question is whether electronic information regarding the presence of a b-vertex can be fed into level-two triggering decisions. (This will clearly be most problematical for high-luminosity running at the LHC.) If not, a level-two 'soft'-lepton b-tag of one or more of the 4 b's in the final state is certainly feasible; for an efficiency of $\sim 10\%$ to $\sim 15\%$ for tagging any one of the 4 b's with $p_T > 15$ GeV, the net tagging efficiency for the 4-b final state would be of order 35% to 48%. Full vertex information could then be recorded and incorporated much later in the analysis. Thus, we believe that the triggering efficiency for the events of interest will be no worse than $\sim 35\%$, and we are hopeful that for low-luminosity running at the LHC the electronic vertex information could be fed in at level-two, in which case triggering efficiency could be near 100%. Thus, the $4b$ final states should prove to be a very powerful tool for Higgs detection at both the Tev* and the LHC.

Acknowledgments

This work was supported in part by the U.S. Department of Energy under grants No. DE-FG03-91ER40674 and No. DE-FG03-90ER40546. Further support was provided by the Davis Institute for High Energy Physics.

References

1. J. Dai, J. Gunion, and R. Vega, Phys. Lett. **B345**, 29 (1995).
2. F. Gianotti (ATLAS), presented at the European Physical Society International Europhysics Conference on High Energy Physics, Brussels, Belgium, July 27 - August 2, 1995, and private communication. R. Kinnunen (CMS), presentation at the Tahoe CMS Week, Tahoe City, CA, September 25-27, 1995.
3. S. Kuhlmann, CDF note CDF/PHYS/ELECTROWEAK/PUBLIC/3342, September, 1995. J. Womersley, private communication.
4. M. Carena, J.R. Espinosa, M. Quiros and C.E.M. Wagner, CERN-TH/95-45; J.A. Casas, J.R. Espinosa, M. Quiros and A. Riotto, Nucl. Phys. **B436**, 3 (1995); H. Haber, R. Hempfling and A. Hoang, CERN-TH/95-216.
5. J. Dai, J. Gunion, and R. Vega, Phys. Lett. **B371**, 71 (1996).
6. Report by the CMS triggering subgroup at CMS Week, March 1996, CERN.

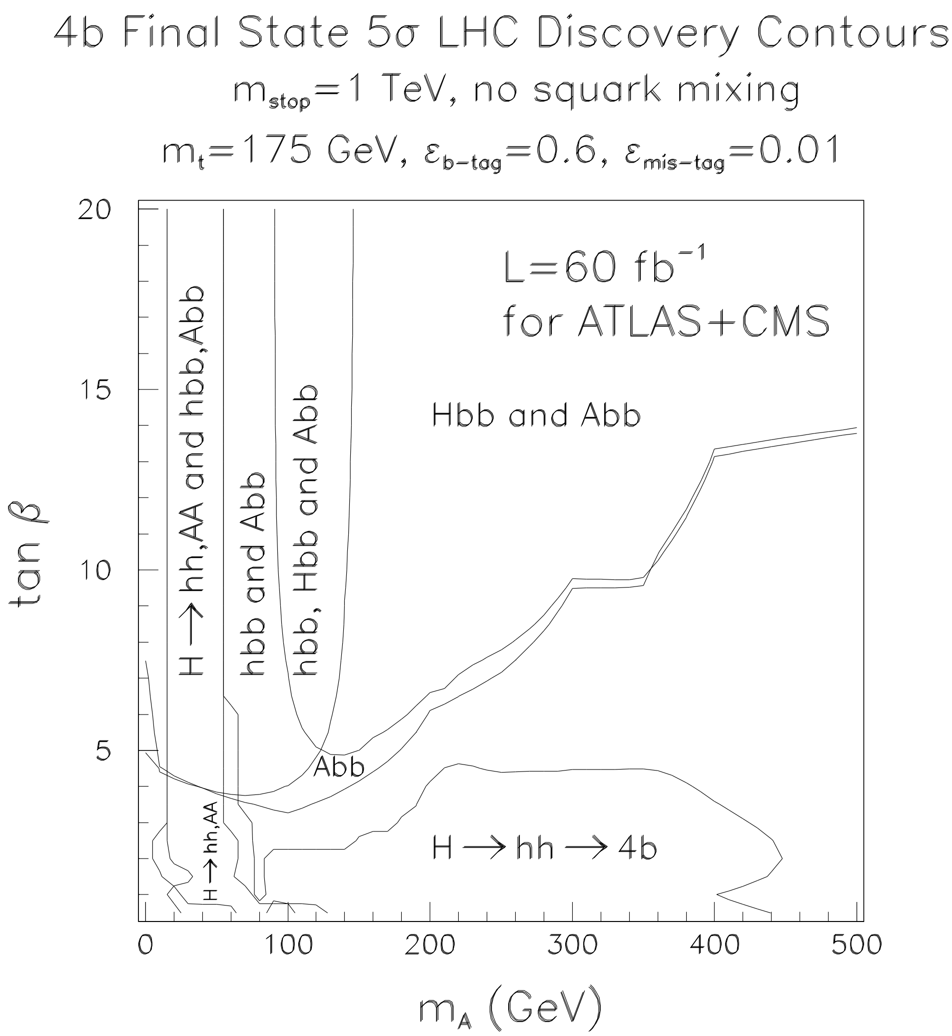

Figure 1: We show the $(m_{A^0}, \tan\beta)$ parameter space regions within which detection of (a) $gg \to b\bar{b}h \to 4b$ ($h = h^0, H^0, A^0$) and/or (b) $gg \to H^0 \to h^0h^0, A^0A^0 \to 4b$ will be possible at the 5σ level at the LHC. We assume $L =$ 30 fb^{-1} for ATLAS and CMS individually (combining their statistics). For (a) [(b)] we require 3 [4] tagged jets (taking $e_{b-tag} = 0.6$, $e_{c-tag} = e_{b-tag}/3$ and $e_{mis-tag} = 0.01$) with $p_T \geq 30$ GeV [15 GeV] and $|\eta| \leq 2.5$. Radiative corrections to Higgs masses and mixing angles [4] are incorporated assuming $m_t = 175$ GeV, $m_{\widetilde{t}} = 1$ TeV and no squark mixing. Event rate reduction due to triggering inefficiencies is assumed to be negligible.

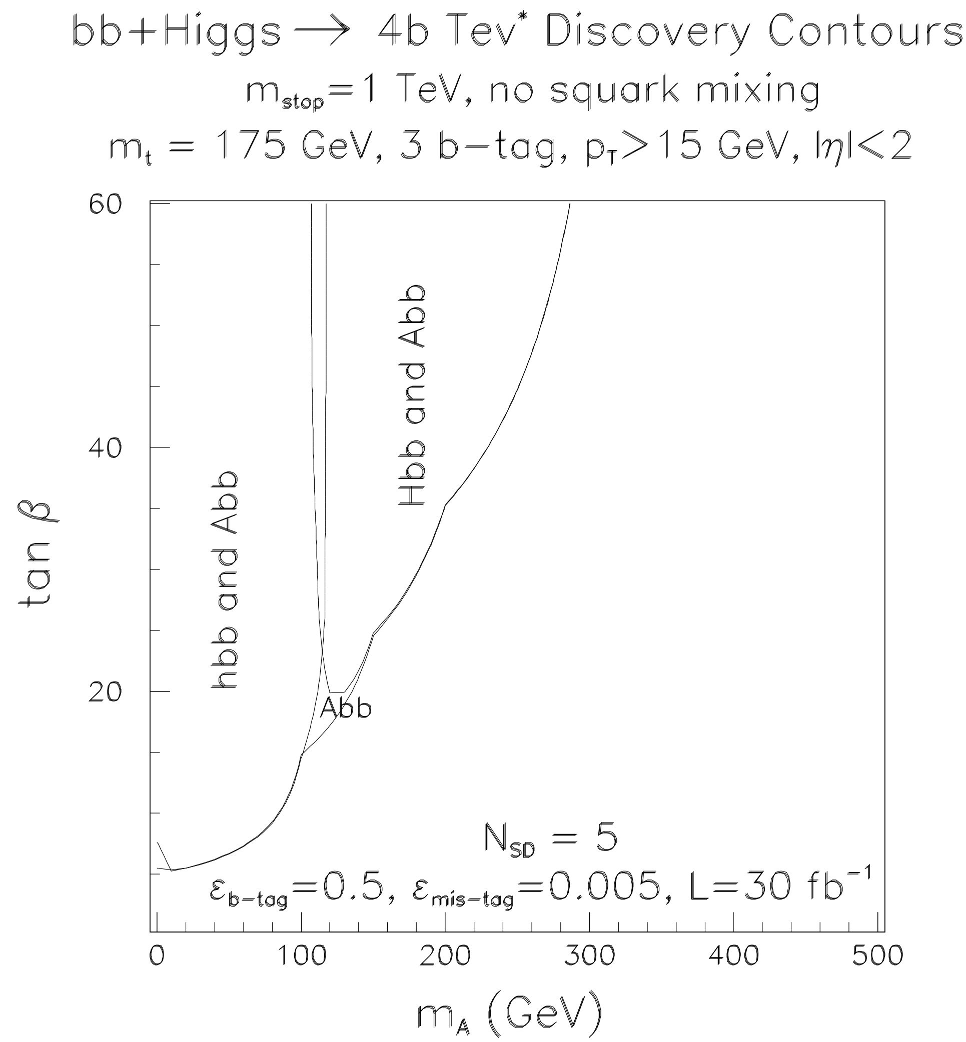

Figure 2: We show the $(m_{A^0}, \tan\beta)$ parameter space regions within which $gg \to b\bar{b}h \to 4b$ ($h = h^0, H^0, A^0$) can be observed at the 5σ level at the Tevatron (operating at $\sqrt{s} = 1.8$ TeV) assuming an integrated luminosity of $L = 30$ fb^{-1}. We require 3 tagged jets (taking $e_{b-tag} = 0.5$, $e_{c-tag} = e_{b-tag}/3$ and $e_{mis-tag} = 0.005$) with $p_T \geq 15$ GeV and $|\eta| \leq 2$. Radiative corrections as in Fig. 1. Event rate reduction due to triggering inefficiencies is assumed to be negligible.